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Comparing Odor Control Treatment Methods on New York Dairy Farms

Peter Wright, Senior Extension Associate

Cornell University/PRO-Dairy, 328 Riley Robb Hall, Ithaca, NY 14853, pew2@cornell.edu

Scott Inglis, Research Support Specialist

Cornell University/PRO-Dairy, 330 Riley Robb Hall, Ithaca, NY 14853, sfi1@cornell.edu

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Abstract. *No single manure treatment system will meet the varied needs of every dairy farm. Farms vary in their resources and their environmental concerns. Some farms have access to more capital, skilled labor, management ability, land resources, water resources, and markets than other farms. Each farm location and watershed may have unique environmental problems from nitrogen, phosphorous, organic loading, pathogens and or odors. Different manure treatment and handling methods will be needed to match the resources and needs of different farms. Manure from storages is already generating many complaints about odor. When manure is stored it starts to decompose anaerobically creating strong odors. Society objects to bad odors as much, if not more, than to dirty water. Therefore, treatment for odor control will become much more common as farms are forced to convert to storing their manure. This paper will explore the variety of treatment systems proposed for use in and near New York State on dairy farms to provide a basis for comparison. Criteria which each farm manager will need to select the treatment system that will best meet their needs will be presented. Farms using composting, biodrying, various anaerobic treatments, and lagoon systems for odor control will be compared using economics, nutrient flow and mass flow data. Economic considerations will include nutrient utilization, by-product sales, and labor needs. Water quality issues will be evaluated based on the mass and nutrient flows. This paper will help farmers and farm advisors evaluate different treatment systems.*

Keywords. Manure, water quality, nutrients, costs

Introduction

Odor is one of the major sources of conflict between dairy producers and the general public. There is no low cost, complete and easy way to control odors from manure.

In a state wide survey of dairy farmers in New York State 61%, 42% and 24% of large (>300 animal units), medium (<300 but > 100 animal units) and small farms (<100 animal units) respectively, received complaints about their operations in the past five years. 42% of these complaints were about odors, with roadway spills being the next highest complaint at 26%. In New York State only 48%, 33%, and 13% of the large, medium, and small farms respectively, had more than 60 days of manure storage (Poe). Farms are completing comprehensive nutrient management plans that require long term storage to avoid spreading manure on saturated ground. The existing manure storage facilities have already produced increased odors. As more farms begin to install and operate storage facilities the complaints and conflicts will increase. With the trends of larger and more concentrated farms, more non-farm rural residents, and more manure storage systems, more farms will experience more problems in dealing with their neighbors over odors.

Objectives

Various treatment systems that reduce or eliminate odor from dairy manure are presented here. General information from farms describing the system, mass and nutrient flows and the costs and management issues of each system are important for dairy producers to understand in order to select the best system for their farm.

Odor report:

To help both the neighbors and the dairy producer evaluate the effect of the treatment system to be installed it is important to gather factual information about the odor coming from the farm. Although measurements of indicator gases such as ammonia and hydrogen sulfide are often done, these gases are often a poor determinate of odor. Ammonia is lighter than air so it will not effect the odor at any distance from the source. There are too many other gases that contribute to the odor from manure for hydrogen sulfide to be a reliable odor indicator. Actual odor unit determinations are quite expensive to obtain.

Using the following odor report that would be available at both the farm and neighboring locations would provide the needed information to determine when and/or if the odor was coming from a particular farm operation and how often it occurred. With this information management decisions could be made to adopt appropriate practices to reduce odor.

Odor Report Number _____ **Location** ______________

Please complete the information below for the odor event you have experienced. this information will help to identify the odor source and management practices that may reduce it.

Duration of the odor: Date _______

Time beginning _______ Time ending ________

Weather conditions: Wind speed ________

Direction wind is blowing from ____________ Temperature _____

Other weather conditions such as precipitation, humidity, etc.

____

Rank the **intensity** of the odor _________

Use a scale ranging from 1 (hardly detectable) to 10 (Very Intense)

Rank the **pleasantness** of the odor _______

Use a scale from 1(very pleasant) to 5 (neutral) to 10 (very unpleasant)

Describe what the odor smells like,

____

Use words like: Silage, Putrid, Ammonia, Rotten egg, Earthy, Musty, Manure, Dead animals etc.,

Any additional comments you may have will be helpful.

____
____
____

Thank you for your help.

Manure treatment systems

Predicting the amounts and concentrations of the nutrients in these systems is difficult. Obtaining representative samples and estimating the losses from biological, chemical, and physical processes in these relatively uncontrolled systems can be difficult. The biological reactions are not monitored or controlled and the temperature, precipitation, and evaporation are uncontrolled in uncovered storage facilities. There can be large variations on the nutrient concentrations.

The capitol costs and operating costs also vary greatly from farm to farm. The costs presented here are a combination of actual costs and projected costs for the various treatment systems. Every farm needs to compare their actual coasts with those used in these estimates to get an accurate estimate for the cost on that particular farm. The number of cows on each farm does affect the annual per cow cost. Smaller farms will have a harder time keeping costs per cow low.

Daily Spread systems are the most common manure handling system in New York State with 39%, 46%, and 58% of large, medium, and small dairy farms respectively handling their manure exclusively by daily spreading (Poe). Fresh manure spread in relatively small amounts in changing locations through out the year doesn't create the odor nuisance that stored partially decomposed manure spread on a large part of the farm creates. There are increased runoff and leaching losses with spreading manure on saturated ground. The operating costs of daily handling of manure can be quite high. The average spreading cost from farms that daily spread in western New York State in one study was $168/cow/year (Wright, 1997).

Liquid Storage facilities will become more common both for cost savings and nutrient retention achieved by managing a storage system. The potential for catastrophic failure of the storage and the spreading system as well as the odor control problems are the main drawbacks to these systems. As all farms move to store more manure and apply it as close to the growing season as possible these drawbacks will increase. The average spreading and storage cost in one study of dairy farms in western New York State was $54/cow/year. This cost does not include any benefits from nutrient savings that might be achieved by storing the liquids.

Composting has been used on excessively bedded dairy manure, separated dairy manure solids and on the drier manure produced by other animal species to reduce odors (Rynk). The costs of composting may be offset by sales of the compost. Most dairy manure is too wet initially to compost well. It needs to have a moisture content of less than 75 % to heat up and start composting easily.

Farms with cheap sources of old hay, waste paper, bark, sawdust, or even recycled compost may be able to add enough solids as an amendment to support a composting operation. Charging tipping fees for the material brought in or aggressively marketing the compost produced can add a profitable enterprise to the dairy operation.

Figure 1 shows the schematic for a 100 cow composting operation. This type of operation even using covers on the composting windrows to shed moisture would have a difficult time operating year round in New York State. Heavy snowfall and precipitation will keep the compost wet until after the spring marketing season. Runoff from the pad will also be a greater concern as the newly mixed compost may still leach nutrients and pathogens. Keeping the amendment dry will also be a management challenge with this operation. If turning is not done regularly, there may be some odors when the compost is finally turned.

Table 1 shows the moisture content and nutrients as a percentage of the wet weight and pounds of manure produced per cow for a composting operation. The amendment used is sawdust with insignificant nutrients.

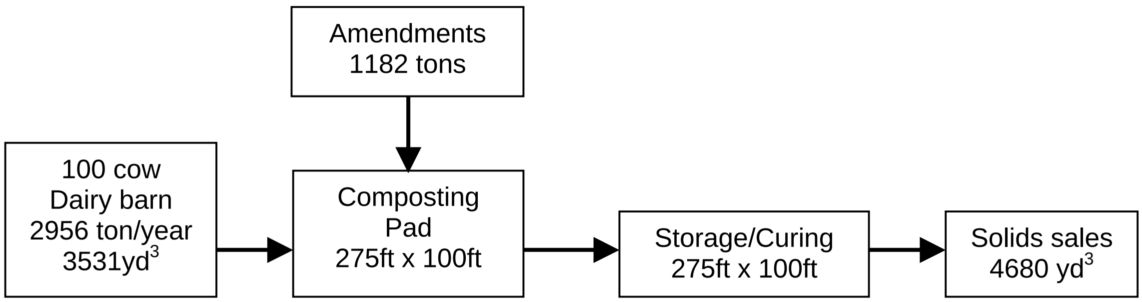

Figure 1. Composting schematic for a 100 cow farm.

Table 1. Composting mass and nutrient flow for a windrow composting operation (St. Jean).

Composting	%M	%N	%P	%K	Lb./cow/day
As produced	90	0.44	0.09	0.29	152
Amendment	17	0	0	0	57
Composted solids	64	0.3	0.06	0.5	86
Nutrients used in land application (Lb./cow/year)	Due to the sale of all solids in this scenario there are no nutrients available to spread on fields.				

The costs and benefits of a typical composting operation is shown in Table 2. The payloader to turn the compost is the largest capital cost. Some farms are experimenting with a portable turner that could be shared or rented to reduce this capital cost. The labor to mix and turn the compost is the largest operating cost, with the cost of the amendment needed to reduce the moisture content the next biggest. The farm would benefit if the amendment could be obtained free or with a tipping fee. The sale of the compost is what keeps this manure treatment system at a reasonable cost. If the price of the compost were increased to $10/ cubic yard, then the annual profit per cow would be about $203/cow/year.

Table 2. Composting capital and operation costs for 100 cow dairy farm (Gabriel).

Capital Cost Items	**Initial Investment**
Composting pad	$9,350
Payloader	$30,000
Compost covers	$3,042
Storage and curing pad	$9,350
Total annual fixed cost (including depreciation and interest)	**$5,612**
Operating Costs	
Repairs and Maintenance	$900
Owner Labor @ 15/hr	$10,944
Amendment @ $5/yd^3	$5,292
Fertilizer	$3,000
Fuel	$732
Sale of Solids $5 per yd^3	-$23,400
Annual operation cost	**-$2,531**
Total annual cost	**$3,031**
Annual cost per cow	**$30**

Biodrying of the manure by recycling dry compost as the amendment in the cow alleys, and using the heat generated in the aerobic decomposition to dry the manure/compost mix with forced air has been proposed (Wright et al 2001). Odor, volume, weight, and pathogen reduction would occur. The schematic of the proposed operation is shown in Figure 2. Equipment and skills for solids handling is already available on most farms so adoption could readily occur on many farms. Storage of solids is safer environmentally than liquid storage because of the lower risk of catastrophic failure. The compost material may be marketed as an income source and to move the nutrients off the farm. The management of the drying process will be critical and the costs of the operation may be high. Additional amendment may be required to achieve the drying needed.

Whether composting with passively aerated windrows or using the biodrying process, most of the nitrogen in the ammonia form is lost to the atmosphere. However, by using less amendment and recycling the compost, the concentration of nutrients in the biodrying, as shown in Table 3, should be higher than regular compost.

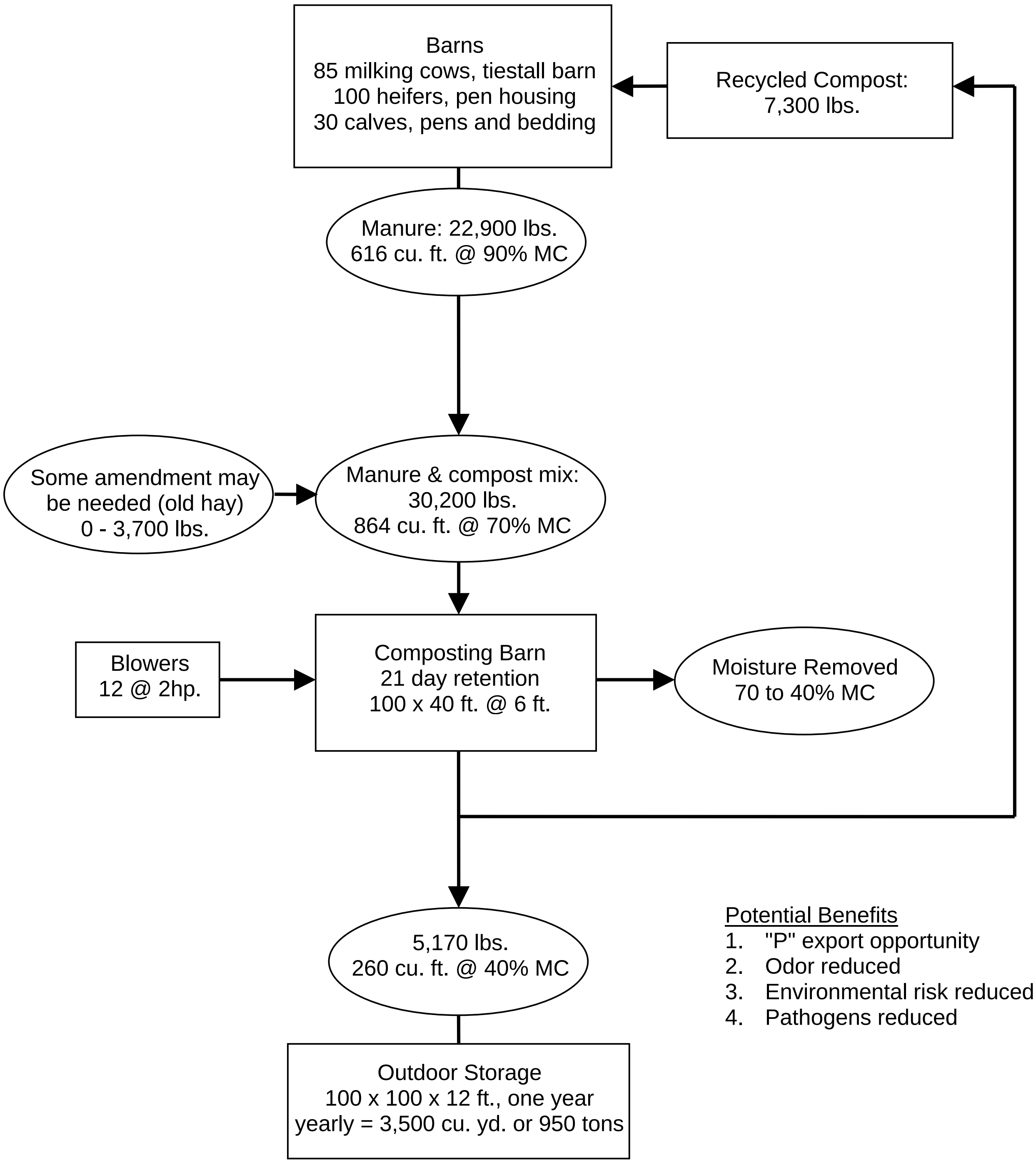

Figure 2. Biodrying schematic for 133 cow equivalents.

Table 3. Expected biodrying mass and nutrient flow.

Biodrying	%M	%N	%P	%K	Lb./cow/day
As produced	90	0.44	0.09	0.29	152
Amendment	17	0	0	0	39
Composted solids	40	0.4	0.1	0.5	94
Nutrients used in land application (Lb./cow/year)	Due to the sale of all solids in this scenario there are no nutrients available to spread on fields.				

While the annual cost per cow is high for this biodrying treatment method, as shown in Table 4, the potential benefits include odor control, all weather operation, limited amendment requirements, less runoff potential from the site, and good quality control of the compost produced. If the solids can be sold at $20 per cubic yard the annual profit/cow of this system would be about $60/cow/year.

Table 4. Biodrying capital and operation costs for 133-cow equivalence.

Capital Cost Items	**Initial Investment**
Compost building	$143,225
Fans/Control system	$22,660
Storage pad	$6,680
Tractor	$45,000
V Spreader	$20,994
Pay Loader	$30,000
Total annual fixed costs (including depreciation and interest)	**$26,167**
Operating costs	
Repairs and maintenance	$6,100
Utilities	$5,300
Hired labor @ $10/hr	$9,090
Fuel	$6,414
Insurance	$400
Bedding	$5,360
Fertilizer	$3,000
Sell compost @ $5 per yd^3	-$17,500
Total annual operating costs	**$15,864**
Total Annual Costs	**$42,031**
Annual per cow cost	**$316**

Anaerobic Digestion for methane production can almost completely control odors from manure. It requires dedicated management to run the biological process, the material handling, and the energy utilization. An engine generator run on the methane produced by the digester can typically provide twice the electricity than the dairy operation needs. It helps to have a use for extra heat since as much as 75 % of the energy produced is wasted as heat when using a engine generator to utilize the biogas. Many of the existing systems have a high capital cost and may be dependent on above market prices for electricity sold. Liquid manure of uniform consistency unmixed with runoff should be used as the feed to a digester.

Evaluations using AgSTAR computer programs supplied by USDA, EPA, and the Department of Energy show that it should be economically feasible for farms with 800+ cows to use anaerobic digestion to reduce the odors, while recovering the costs by producing electricity (Jewell 1997). Selling the electricity through a utility is a problem. Keeping both the initial capital costs and the operating costs low will be critical to the economic success of this treatment.

The nutrients are not removed by anaerobic digestion as shown in Table 5. There is a small shift of about 5% of the organic nitrogen to ammonia during digestion. This may be a benefit to crop production if the effluent is applied right away. During storage the ammonia may volatilize. Nutrients (and solids) will tend to settle out of the anaerobic effluent. There may be as much as 5 to 8 times less nutrients in the top layers of the effluent storage compared to the bottom sludge. This explains the seeming lower percentage of nutrients in the material coming from the storage. The plastic lined storage does not have provisions for strong agitation, so the nutrients settling in the bottom may build up. There is a loss of solids in this treatment process resulting in a 2 -3 % increase in the moisture content of the effluent compared to the raw manure entering the system. The increased moisture content makes the liquid effluent very suitable to irrigation. Irrigating low odor liquids in the summer meets environmental constraints while reducing peak labor needs compared to spring application of stored liquid manure. The odor reduction is greatly appreciated by the neighbors.

The plug flow digester on this farm has a 20 day Hydraulic Retention Time (HRT) for 1000 cows. Only 500 cows presently use the digester. The engine generator was purchased used, reducing the initial cost but increasing the maintenance cost. The screw press separator works efficiently with less maintenance on the digested effluent (Wright and Perschke). A separated solids operation as shown in Figure 3 is an additional benefit with this system. A screwpress separator works very well on digested effluent.

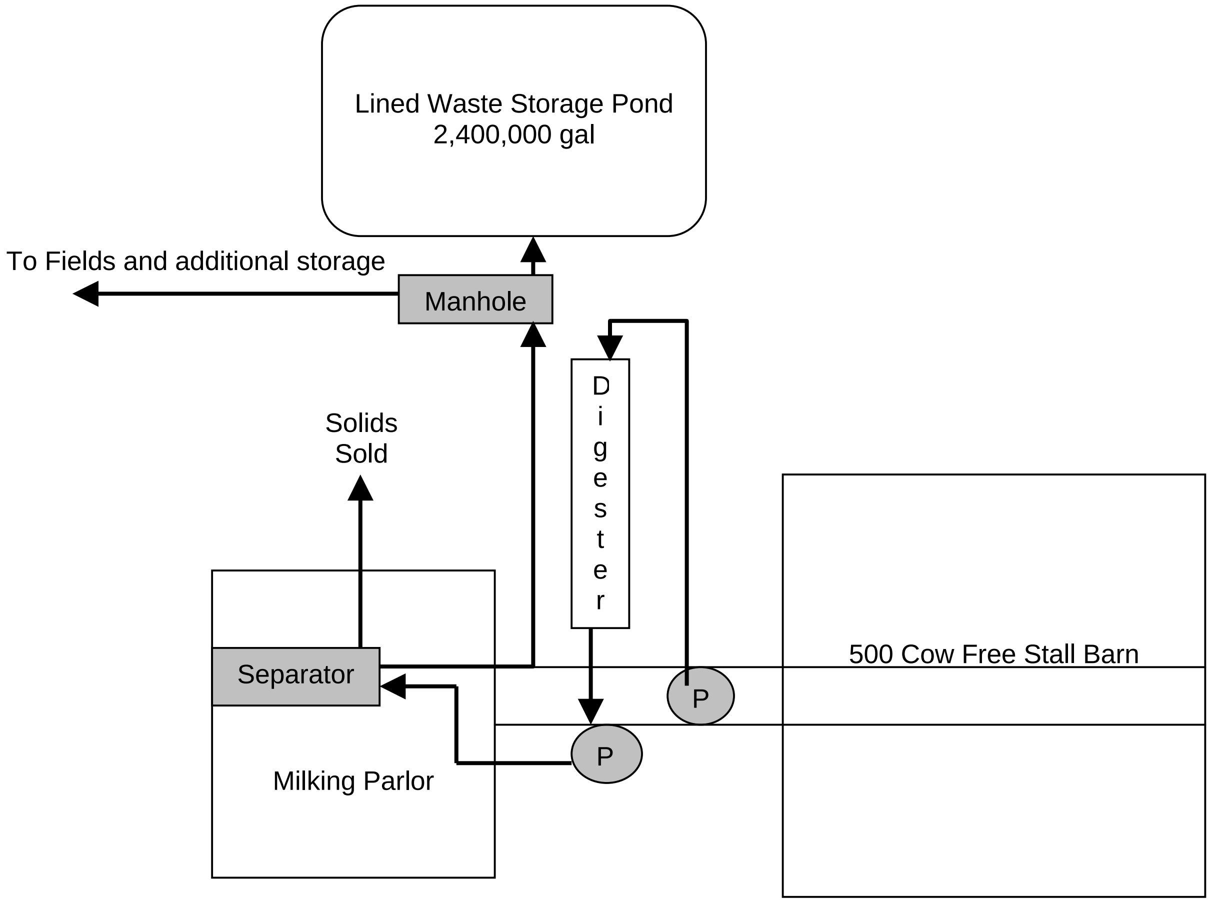

Figure 3. Anaerobic digester schematic for a 500 cow dairy farm.

Table 5. Anaerobic digester mass and nutrient flow.

Anaerobic digester	%M	%N	%P	%K	Lb./cow/day
As produced per day	90	0.44	0.09	0.29	152
After digestion per day	93	0.45	0.07	0.26	146
Separated liquid per day	95	0.43	0.06	0.28	126
Separated solids per day	77	0.51	0.11	0.26	21
From storage per day	98	0.27	0.02	0.16	165
Nutrients used in land application (Lb./cow/year)		163	12	97	

The capital cost of the digester and engine generator are the largest costs in this system. This farm bought a used engine generator so its costs were less than farms with all new equipment. The sale of the solids is a significant income for this system. The electric income mainly comes from replacing the cost of purchased electricity used on the farm. Because there is no system set up to receive a premium for green power, the surplus electricity produced is sold back to the utility at only their deferred operating expenses.

Table 6. Anaerobic digester capital and operation costs for 500 cows.

Capital Cost Items	**Initial Investment**
Concrete digester	$160,000
Earthen storage	$60,000
Separator	$25,000
Separator building	$25,000
Irrigation system	$45,000
Pump	$12,000
Engine generator & electric equipment	$63,000
Total annual fixed cost (including interest and depreciation)	**$35,175**
Operating Costs	
Repairs/Maintenance	$15,000
Management Labor @ $20/hr	$6,920
Hired labor @ $10/hr	$1,800
Sale of electricity	-$24,000
Sale of Solids @ $5/$yd^3$	-$20,278
Total annual operating cost	**-$19,208**
Total annual cost	**$15,967**
Annual per cow cost	**$32**

Fixed Film anaerobic digestion utilizes retained microbes to reduce the HRT to 5-10 days instead of the typical 20-25 days (Wilkie). The microbes are retained on plastic corrugated 4 inch diameter tubes set vertically in the digestion tank. Separated liquid dairy manure will flow from the bottom to the top of the digester. It will be degraded by the large numbers of methanogenic bacteria clinging to the tubes. This reduces the cost of the digester and should allow quicker and less expensive start up, since a smaller volume will need to be heated than with a larger typical digester.

The solids are removed prior to digestion to reduce the loading and to prevent clogging. It is estimated that 30% of the potential gas production is lost as about 25% of the mass is removed through separation of the solids. The solids can be composted and/or dried with the heat from the boiler.

The methane gas will be utilized to heat the digester, provide hot water for the farm, and dry the solids. This system is best used on farms that either have low electric costs or are too small to justify the expense of a generator and electric hook up to the utility, yet want the odor control that anaerobic digestion provides.

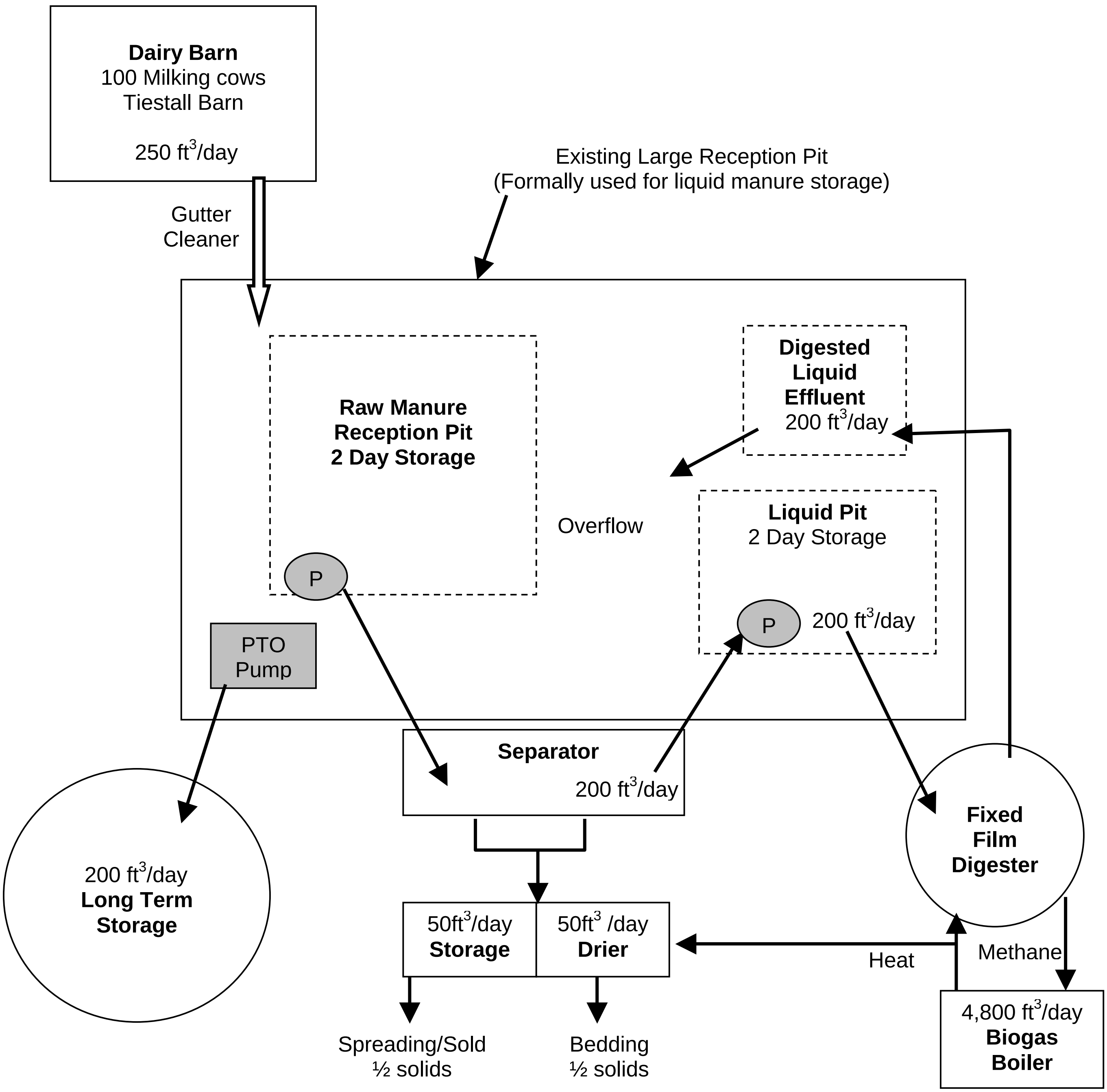

Figure 4. Fixed film schematic for a 100 cow dairy farm.

Table 7. Fixed film mass and nutrient flow.

Fixed Film	%M	%N	%P	%K	Lb./cow/day
As produced	90	0.44	0.09	0.29	152
Separated solids	72	0.4	0.1	0.3	36
Separated liquids	94	0.4	0.1	0.3	116
Digested liquids	96	0.4	0.1	0.3	114
Nutrients used in land application (Lb./cow/year)		193	48	145	

This system is being installed on a farm with an existing liquid storage as shown in Figure 4. The producer dislikes his existing system because of the odors produced and the need to empty it in the spring and fall instead of on hay crops during the summer. He can not spread the stored liquid manure on all his fields due to complaints from the neighbors. Fields that have low organic matter can not be improved because the neighbors object to the extreme odors from manure spreading. Some neighbors refuse to rent land to him that is close to his farmstead because of the manure odors, forcing him to travel further from his operation to do fieldwork.

The anticipated mass and nutrient flows, shown in Table 7,show a greater preservation of nutrients compared to the stored manure from the previous plug flow digester. This is due to two factors: the concrete storage with it's decreased surface area to volume ratio compared to the earthen storage allows less volatilization of ammonia, and the full agitation they can achieve compared to the plastic lined pit where they limit agitation for fear of damaging the liner. Nutrients won't remain concentrated in the bottom of the concrete storage as it is being emptied.

Table 8 shows the costs of the completed fixed film digester system. Although this is a high cost spread over a few cows, this system may be needed to control odors while still using a liquid manure storage facility.

Table 8. Fixed Film capital and operation costs for 100 cow dairy farm.

Capital Cost Items	**Initial Investment**
Manure Treatment Facility	$63,000
Manure Facility Equipment	$74,150
Concrete manure storage	$160,000
Liquid Spreader	$14,000
Solids Spreader	$2,640
Existing pumps	$12,000
Small Tractor	$10,000
Total Annual fixed costs (including depreciation and interest)	**$38,040**
Operating Costs	
Repairs/maintenance	$6,600
Utilities	$2,500
Management labor @20/hr	$9,240
Fuel	$330
Insurance	$400
Tractor rental	$5,280
Bedding savings	-$5,400

Field usage	-$4,500
Fertilizer	-$1,000
Improved soils	-$1,000
Solid sales	-$1,200
Total annual operating costs	**$11,250**

Total Annual Costs	**$49,290**
Annual per cow cost	**$492**

The **Bion** System that uses lagoons as a treatment system has reduced odors on some farms in New York State (Wright and Perschke). The system consists of shallow ponds (1-2 foot deep) that settle the solids for recovery and potential sale as shown in Figure 5. Then the liquids go to a faculatative deep pond and are recycled as flush water for the cow alleys. A large land area for the treatment system is needed. Odor control has been good both onsite and during irrigation of the liquids.

This system loses about 25% of the nitrogen to the atmosphere and can catch a lot of extra water on the surface area of the large ponds. The solids from this system typically contain 40% of the nitrogen and 50% of the phosphorous. The liquids typically contain 35% of the nitrogen and the remaining 50% of the phosphorous. Bion systems with the addition of a series of recirculating terraces and overland flow treatment have been used to completely reduce the total nutrients and mass of effluent from a 350 cow dairy with 100 acres of land (Wright et al 2000).

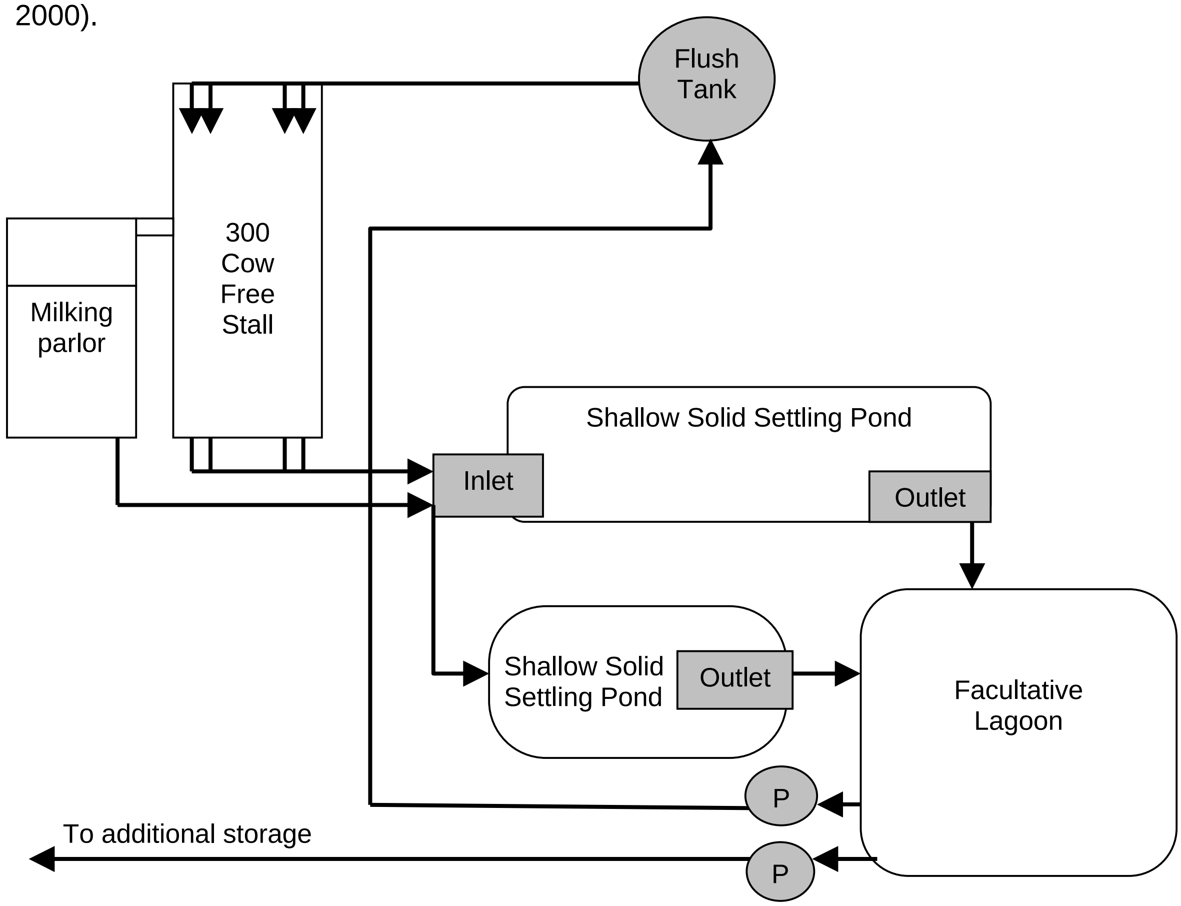

Figure 5. Bion system schematic.

Table 9. Bion system mass and nutrient flow.

Bion	%M	%N	%P	%K	Lb./cow/day
As produced	90	0.44	0.09	0.30	152
Separated liquid	99	0.08	0.01	0.07	135
Separated solids	83	0.37	0.10	0.07	17.5
Nutrients used in land application (Lb./cow/year)		39	5	35	

Although there is extra expense in the design work and a reduced solid price due to a commission on sales, the system appeals to farms who want the management help of professionals to design and manage the treatment system, and help in marketing their product. The use of flush water recycling to build the population of microbes, the sale of the solids, and the low odor, dilute effluent make this an ideal system for farms that are set up to flush, have a limited land base, and are close to sensitive neighbors.

Table 10. Bion capital and operation costs for 350 cows.

Capital Cost Items	**Initial Investment**
Design Work	$43,040
Flush system	$75,554
Irrigation system	$45,000
Lagoon treatment system w/ aerators	$134,520
Total annual fixed cost (including depreciation and interest)	**$27,725**
Operating Costs	
Repairs and maintenance	$2,105
Utilities	$18,000
Hired Labor @ $10/hr	$4,260
Rental Back hoe $70 per hr	$3,360
Sale of Solids 3.25 per yd^3	-$15,925
Total Annual Operating costs	**$11,800**
Total Annual Costs	**$36,009**
Annual Per cow cost	**$102**

The **NC lagoon** systems have had some success in using mechanical separation to remove the solids. A small retention pond removes additional solids and then two or more lagoons in series continue to degrade the manure liquids as shown in Figure 6 (Rensch). Often aerators are added to help break down the liquid manure before recycling back to the barns as flush water. The liquids from the top of the lagoon can be irrigated at a relatively high rate since they are relatively low in nutrients. The more nutrient rich and concentrated material from the bottom of the lagoon can be hauled further from the site and applied at a nutrient loading rate. The solids separated manually can be composted and then used on site for bedding or sold offsite.

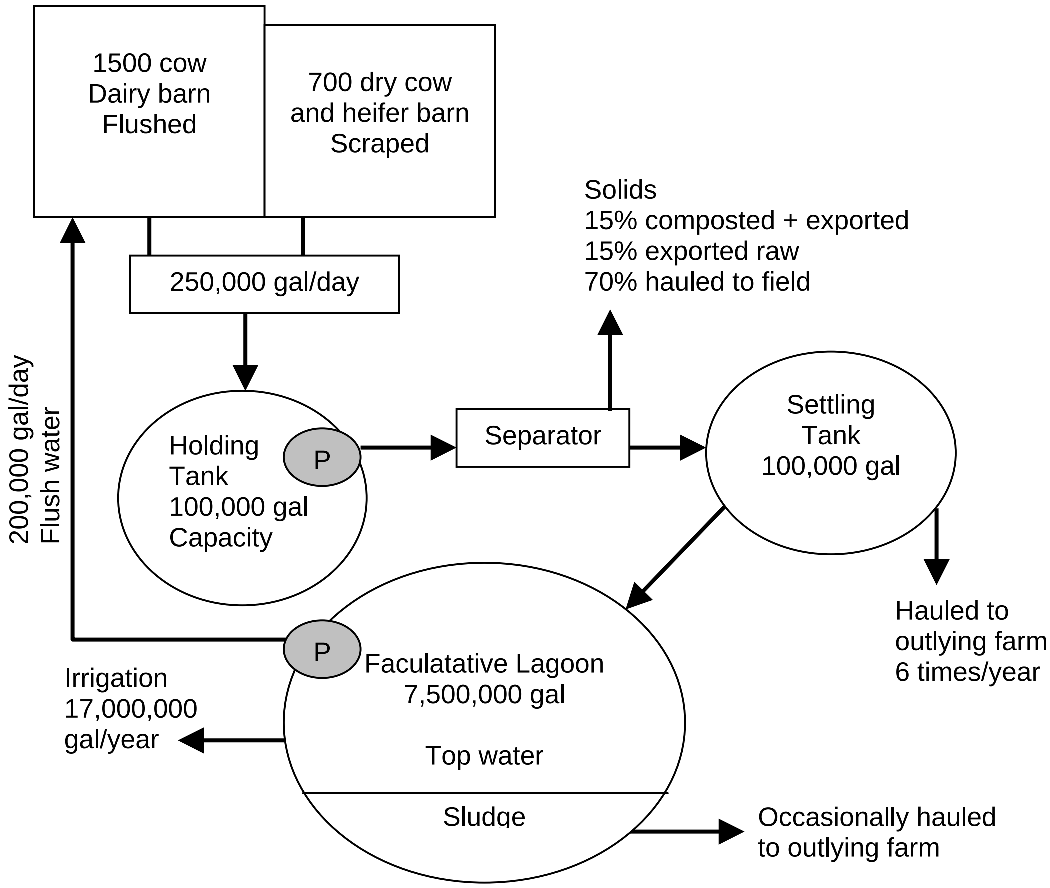

Figure 6. NC system schematic for a 1980 cow equivalents.

The nutrient content of the NC system components are shown in Table 11. The roller press separator seems to work well with the fairly dilute flushed manure. Since the liquids are recycled there is not a large increase in the amount of liquids to be spread. The amount of sludge to be spread will vary depending on how much is removed from the facultative lagoon each year.

Table 11. NC system mass and nutrient flow.

NC system	%M	%N	%P	%K	Lb./cow/day
As produced	90	0.44	0.09	0.30	152
Before separation	98	0.4	0.07	0.16	1200
Separated solids	75	0.38	0.04	0.10	22
Separated liquids (top water)	99	0.15	0.01	0.07	200
Sludge	94	0.28	0.05	0.11	7+
Nutrients used in land application (Lb./cow/year)		138	11	60	

The low annual costs per cow for this system, as shown in Table 12, shows the value of economics of scale. By having 1980 cow equivalents large equipment costs can be spread over many cows, keeping per cow costs low.

Table 12. NC system capital and operation costs for 1980 cow equivalent.

Capital Cost Items	**Initial Investment**
Earthen storage	$55,700
Separator	$19,000
Separator building	$25,000
Flush system	$95,000
Irrigation system	$79,000
Concrete holding tank	$20,000
Concrete settling tank	$20,000
Truck to haul sludge	$35,000
Loader	$30,000
Storage pump	$10,000
Aeration	$6,325
Composting (15% total solids)	$5,000
Storage pad	$6,000
Total annual fixed cost (including interest and depreciation)	**$42,789**
Operating Costs	
Repairs/Maintenance	$6,003
Utilities	$11,966
Hired Labor @ $15/hr	$10,800
Sale of solids @$5yd^3 (30% of produced)	-$31,680
Total annual operating cost	**-$160**
Total annual cost	**$42,628**
Annual per cow cost	**$22**

Overall, manure handling and treatment options will have different relative values on farms as shown in Table 13. Of course every farm is different both in their resources and their goals. This scale is an attempt to compare the systems with each other. For a specific farm, it would have to be reevaluated to reflect actual conditions for that farm.

Table 13. Relative rating of various criteria on different manure handling and treatment options.

Criteria	Daily spread	Liquid Storage	Compost	Biodrying	Anaerobic digestion	Fixed film digestion	Bion	NC Lagoon system
Runoff & Leaching reduction	Poor	Medium	Good	Good	Good	Good	Good	Good
Odors	Medium	Poor	Good	Good	Good	Good	Good	Good
Small farm	Good	Poor	Good	Good	Poor	Medium	Good	Good
Large farm	Poor	Medium	Poor	Medium	Good	Medium	Good	Good
N reduced	Medium	Medium	Good	Good	Medium	Medium	Good	Good
P export	Poor	Poor	Good	Good	Poor	Medium	Good	Medium
Pathogen Control	Poor	Medium	Good	Good	Good	Medium	Medium	Medium
Nutrient retention	Poor	Medium	Medium	Medium	Good	Good	Poor	Poor
Management ease	Good	Medium	Medium	Poor	Poor	Poor	Poor	Poor
Capital Costs	Good	Medium	Good	Medium	Poor	Medium	Medium	Medium
Operating Costs	Good	Medium	Poor	Medium	Poor	Poor	Poor	Medium
Material Sales	Poor	Poor	Good	Good	Medium	Medium	Medium	Medium
Energy sales	Poor	Poor	Poor	Poor	Good	Poor	Poor	Poor
Combined costs/cow/year	$168	$54	$30	$316	$32	$492	$102	$22

Conclusion

- There are advantages and disadvantages to each system that may be more or less important to each farm. Different treatment systems may be better suited to each different farm. Each farm should carefully evaluate their needs and the potential benefits from each manure treatment system.
- There are existing treatment systems that work well. Odors are significantly controlled on some systems allowing nutrients to be utilized at the environmentally appropriate time.
- Documentation of the mass and nutrient flows and the design processes are needed for farmers to make decisions. Each different manure handling and treatment system needs to be evaluated for its effect on the nutrients that will be land applied.
- Nutrient utilization and by-product sales are important in reducing the cost of a manure handling system. Marketing the separated solids or other by-products and fully utilizing the nutrients in the manure can help pay for treatment systems. Labor costs and capital costs will vary depending on which system is selected.
- More research is needed not only to develop cost effective manure treatment systems, but also to document their performance with more consistent mass, nutrient, and economic data.

References

Gabriel, Aaron. Is Composting Profitable. Cornell Cooperative Extension Agricultural News Serving Eastern New York. Vol. 27 No. 10, p. 12-15. Ballston Spa, NY 12020.

Geohring, Larry D., Peter E. Wright, and Tammo S. Steenhuis. 1998. Preferential Flow of Liquid Manure to Subsurface Drains, Drainage in the 21st Century: Food Production and the Environment. Proceedings of the 7th Annual Drainage Symposium March 8-10, 1998. St. Joseph, Mich.: ASAE.

Gregory Poe, Nelson Bills, Barbara Bellows, Patricia Crosscombe, Rick Koelsch, Michael Kreher, and Peter Wright. Documenting the Status of Dairy Manure Management in New York: Current Practices and Willingness to Participate in Voluntary Programs. Staff Paper SP 99-03. September 1999. Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, New York 14853-7801.

Hilborn, Donald. Manure Handling Systems: Economic and Environmental Comparison. Proceedings from the Animal Agriculture and the Environment North American Conference, Rochester, NY. Dec 11-13, 1996. Natural Resource Agricultural Engineering Service, 152 Riley-Robb Hall, Ithaca, New York 14853-5701.

Jewell, W. J., P. E. Wright. 1999. Resource-Recovery Animal Waste Treatment. ASAE Meeting Paper No. 994025. St. Joseph, Mich.: ASAE.

Jewell, William J., P. E. Wright, N. P. Fleszar, G. Green, A. Safinski, A. Zucker. Evaluation of Anaerobic Digestion Options for Groups of Dairy Farms in Upstate New York. Final Report, June 1997. Department of Agricultural and Biological Engineering, College of Life Sciences, Cornell University, Ithaca, New York 14853.

Rensch, Tim. On-Farm System - Utilizing Solids Separation, Low-Rate Land Application, and Aerated Static Pile Composting at Frey Dairy Farms. NRAES-143. Proceedings from Dairy Manure Systems, Equipment and Technology, Rochester, NY. March 20-22, 2001. Natural Resource Agricultural Engineering Service, 152 Riley-Robb Hall, Ithaca, New York 14853-5701.

Rynk, R. ed. On Farm Composting Manual. NRAES-54. Natural Resource Agricultural Engineering Service, 152 Riley-Robb Hall, Ithaca, New York 14853-5701.

St. Jean, R. On-Farm Composting Techniques: Understanding Nitrogen and Carbon Conservation. COESA Report No: RED/MAN-003/97. http://res2.agr.ca/london/gpres/report/rep13sum.html.

Weeks, Stan. Fixed-Film Anaerobic Digestion. NRAES-143. Proceedings from Dairy Manure Systems, Equipment and Technology, Rochester, NY. March 20-22, 2001. Natural Resource, Agriculture, and Engineering Service, 152 Riley-Robb Hall, Ithaca, New York 14853-5701.

Wilkie, Ann C. Anaerobic Digestion of Livestock Wastes: A Sustainable Approach to Odor Abatement. 1998. Proceedings of the North Carolina 1998 Conference and Beef Symposium, p. 5-16. North Carolina Pork Council, Raleigh, North Carolina.

Wright, Peter. Manure Treatment and Handling Options. North Central Extension-Industry Soil Fertility Conference. St. Louis, Missouri. Nov. 15-16, 2000. Proceedings Vol.16 p. 56-65. Published by Potash & Phosphate Institute, 772 22nd Avenue South Brookings, SD 57006.

Wright, Peter, and A. Edward Staehr. 1999. Environmental Factors to Consider When Expanding Dairies. NRAES-95. Natural Resource, Agriculture, and Engineering Service, 152 Riley-Robb Hall, Ithaca, New York 14853-5701.

Wright, Peter, and S. P. Perschke. 1998. Anaerobic Digestion and Wetland Treatment Case Study: Comparing Two Manure Odor Control Systems for Dairy Farms. ASAE Annual Meeting Paper No. 984105. St. Joseph, Mich.: ASAE.

Wright, Peter E. 1997. Survey of Manure Spreading Costs around York, New York. ASAE Meeting Paper No. 972040. St. Joseph, Mich.: ASAE.

Wright, Peter E., S. P. Perschke, and J. Derringer. 2000. Lagoon and Wetland Treatment of Dairy Manure. ASAE Meeting Paper No. 00-4126. St. Joseph, Mich.: ASAE.

Wright, Peter, Curt Gooch, and Scott Inglis. 2001. Biodrying Dairy Manure: Initial Experiences. ASAE Meeting Paper No. 01-2292. St. Joseph, Mich.: ASAE.